DEVELOPMENT OF A NOVEL VIBRATING REACTOR FOR TESTING BIO-OIL GASIFICATION CATALYSTS

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TEST REACTORS FOR CATALYTIC ENDOTHERMIC REACTIONS

- **Many important catalytic reactions are endothermic e.g.:**
  - catalytic cracking
  - gasification

- **Issues with traditional test reactors:**
  - Heat is transferred from the wall into reactor
    - Low heat transfer coefficient
    - → High temperature gradient
    - → Parasitic thermal cracking reactions
  - Seals for agitator may leak

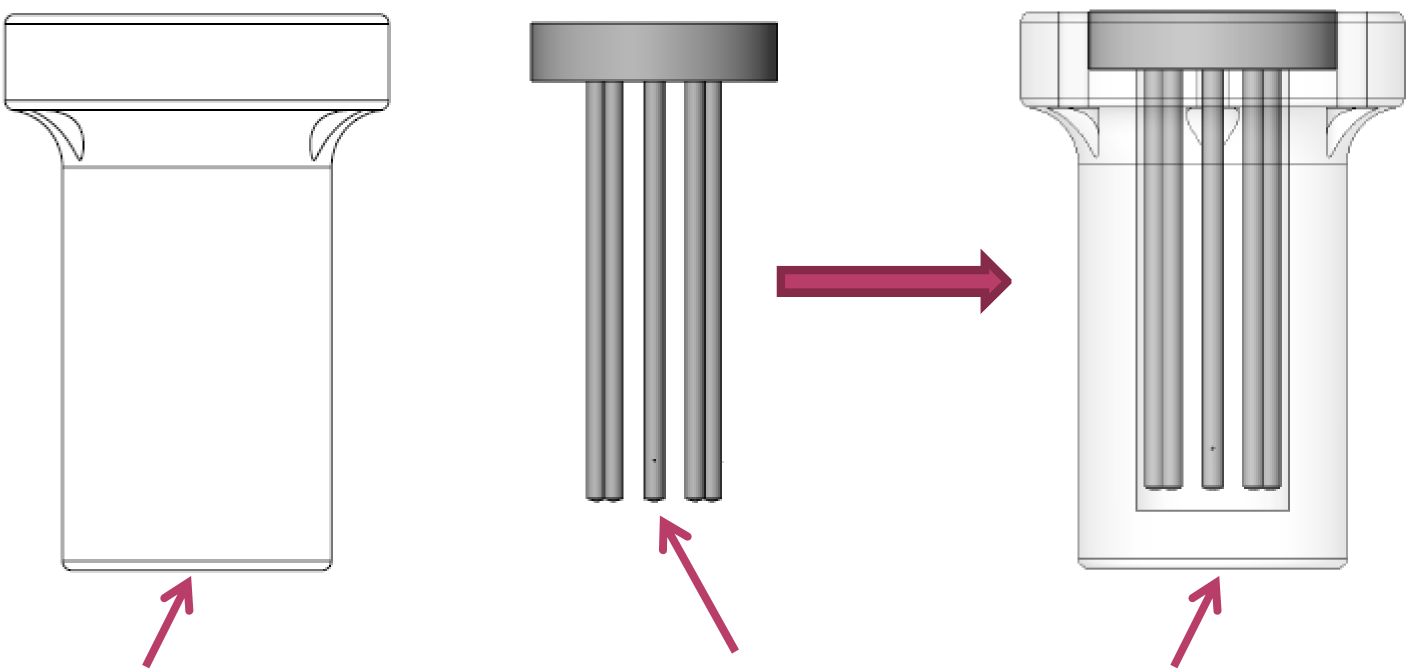
OBJECTIVES

- Develop new test reactor:
  - Batch-wise reactor
  - Low temperature difference between heating surface and catalyst bed
    → induction heating of rods within bed
  - No mechanical seal
    → jiggle bed (up and down motion)
- Test new reactor

INDUCTION HEATING

- **Advantages of induction heating**:
  - Very fast heating rate
  - Heat transfer from within the bed, not from the wall
    - Temperature profile as in industrial units

CERAMIC CRUCIBLE AND INDUCTION HEATING ELEMENTS



Ceramic crucible
Alumina 99.8%

Induction heating elements
8 Inconel heating wires

Reaction zone
of the JBR

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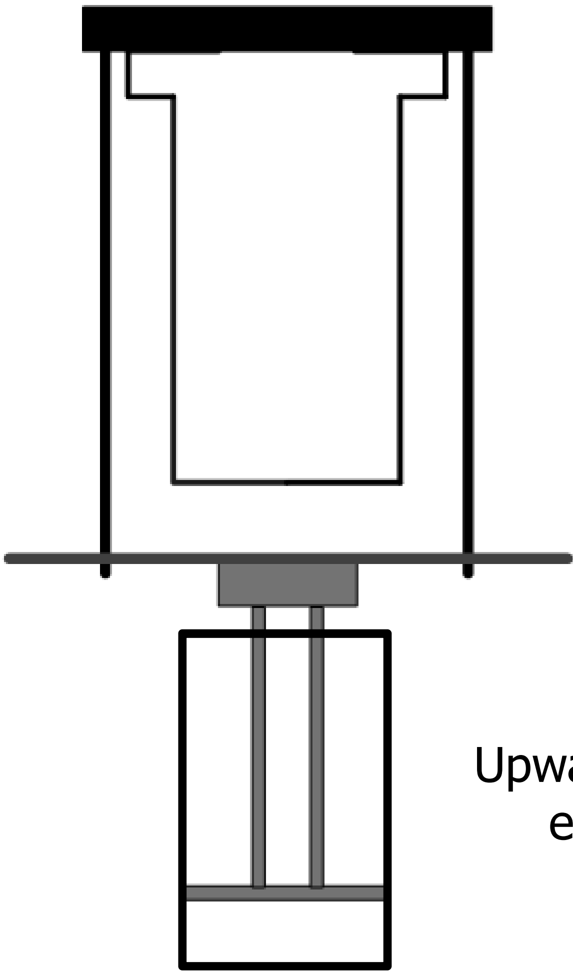
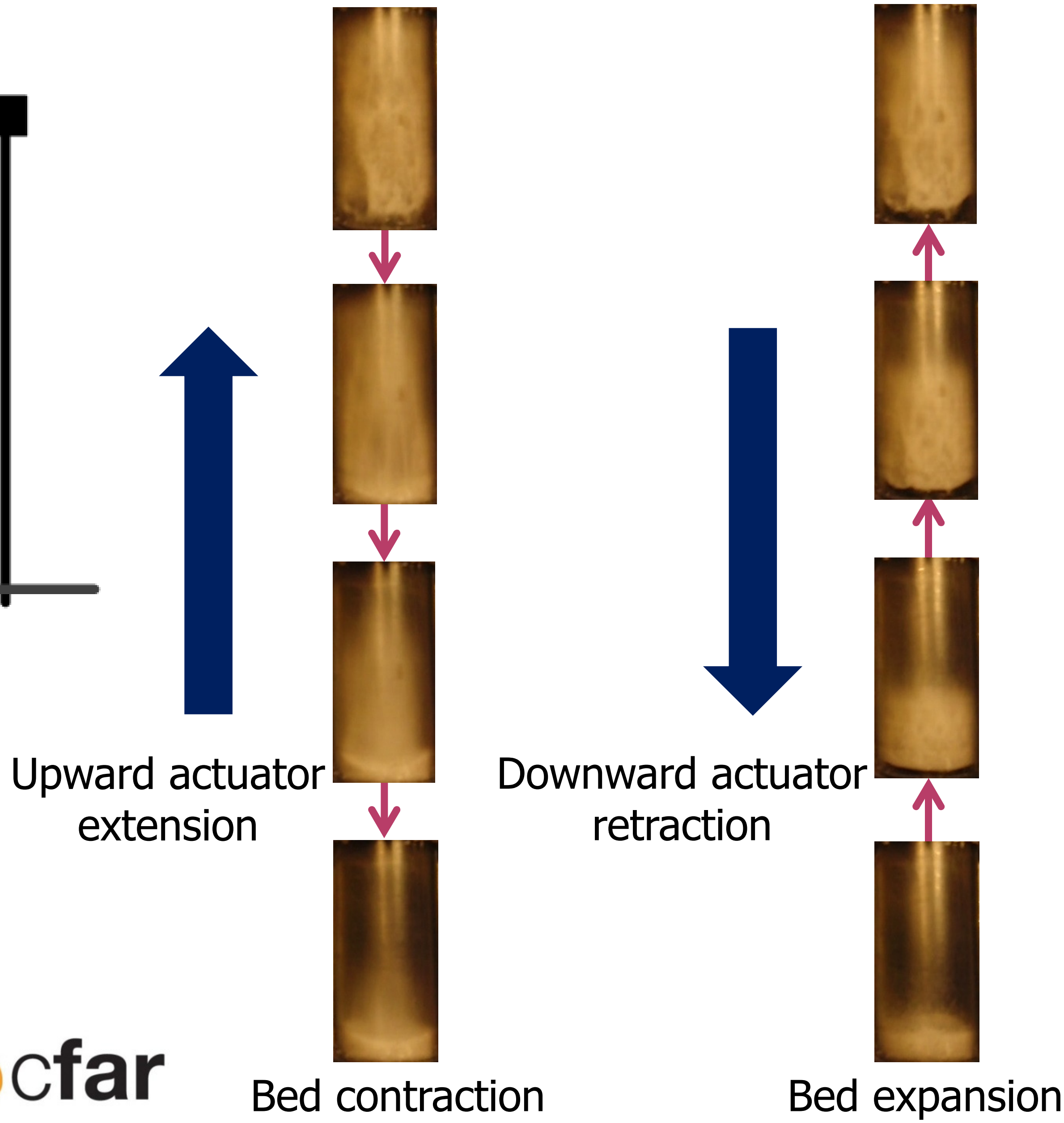
AGITATION OF JBR





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EXPLODED VIEW OF THE JBR

1. on/off feed valves
2. Inlet of carrier gas
3. Thermocouple
4. Inlet of feed and carrier gas
5. Ceramic crucible with insulation
6. Insulation disk
7. Insulation disk
8. Linear pneumatic actuator
9. Outlet gas valve
10. Stainless steel support rods
11. Copper coil
12. Copper disk
13. aluminum disk
14. Stainless steel scalloped disk

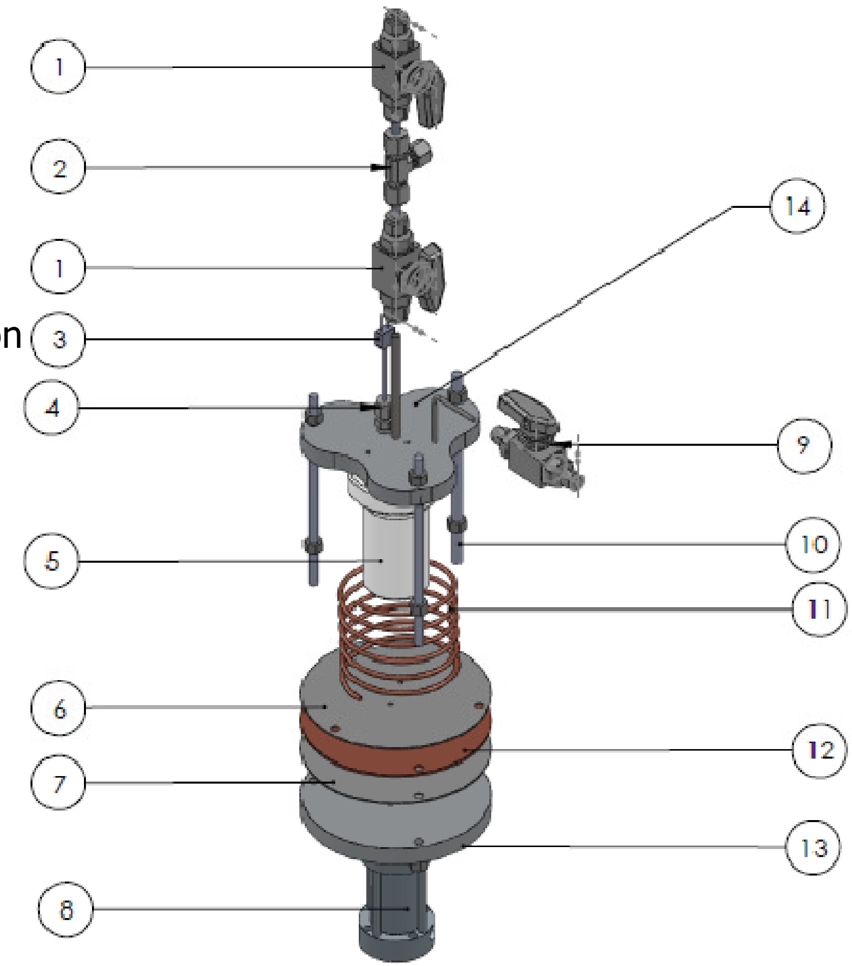
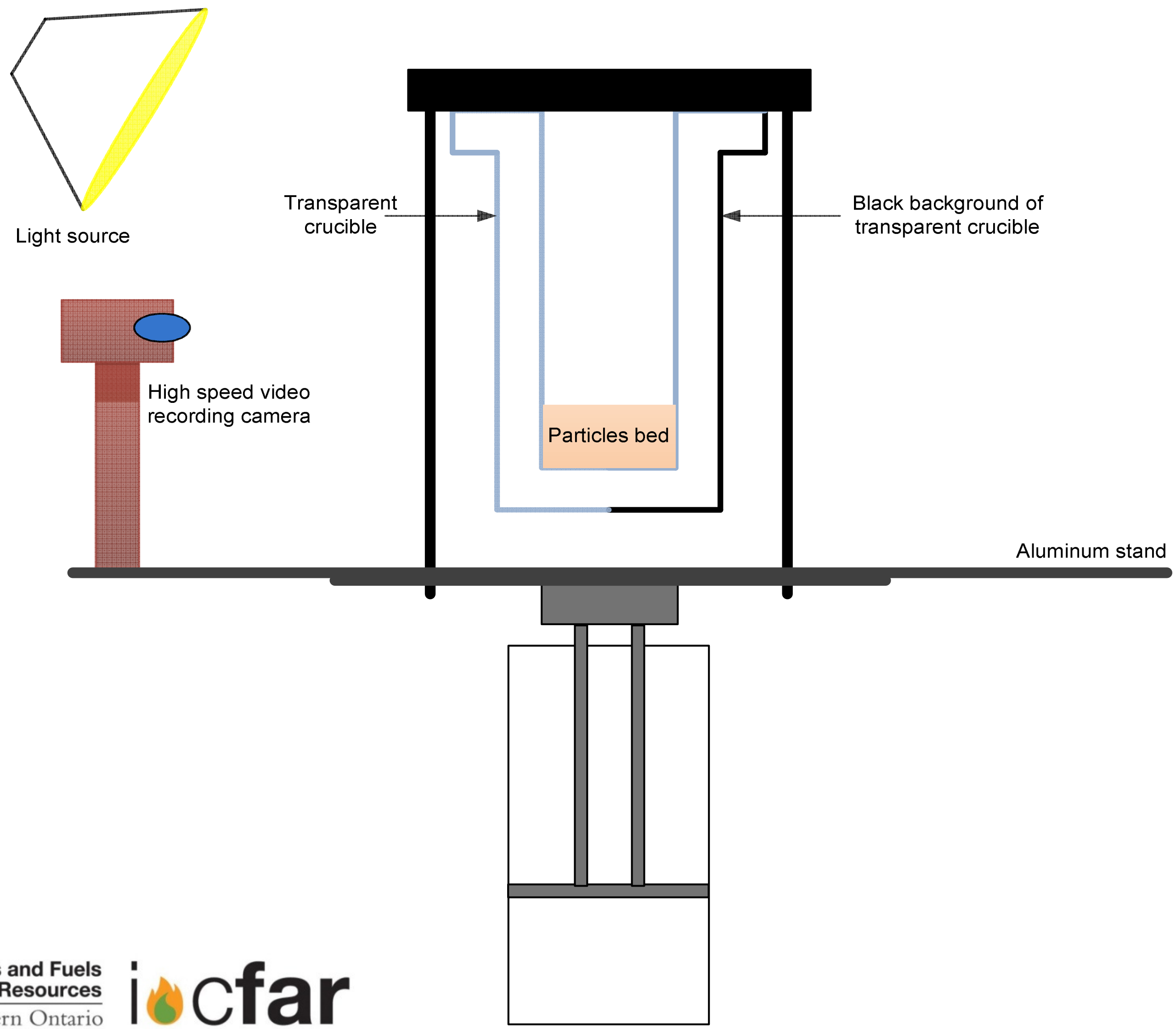


IMAGE PROCESSING SETUP



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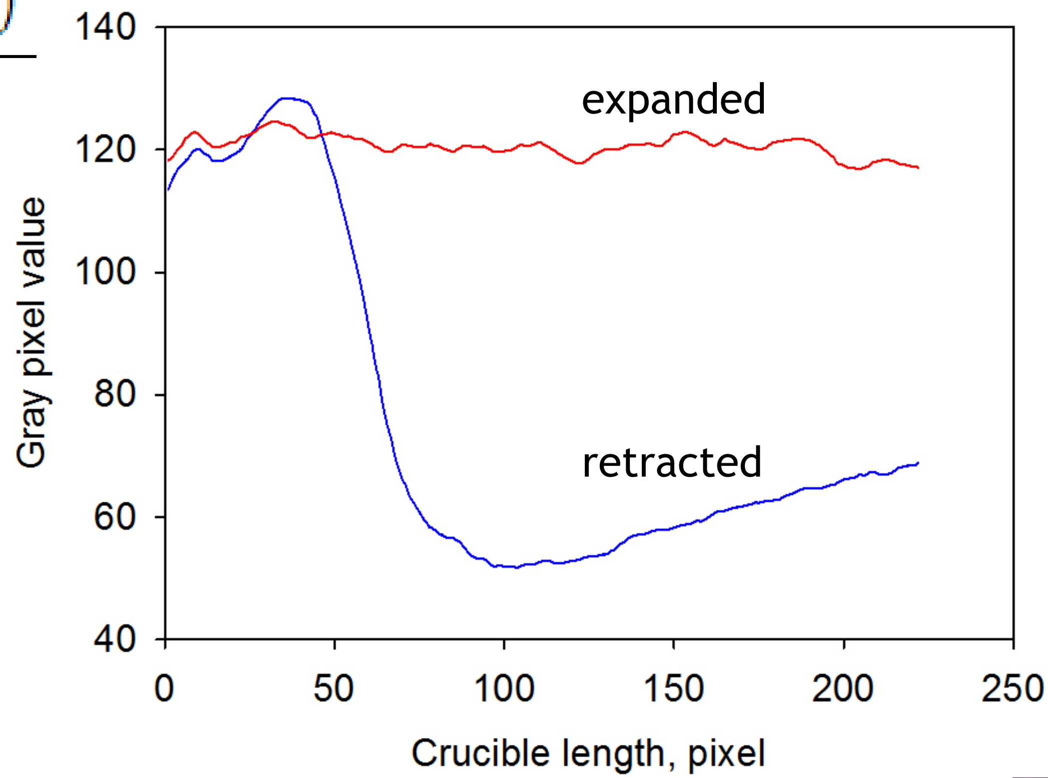
DIGITIZED GRAY PICTURES

$$CV_{space} = \left(\frac{\sigma}{\mu}\right)_{space} = \frac{\sqrt{\frac{1}{N_i}\sum_i \left(y_{i,j} - \frac{\sum_i y_{i,j}}{N_i}\right)^2}}{\frac{\sum_i y_{i,j}}{N_i}}$$

Expanded bed

Retracted bed



Variation of the horizontally averaged gray value along the crucible length

Bed of sand particles: 10 g mass and size distribution of 149-212 µm

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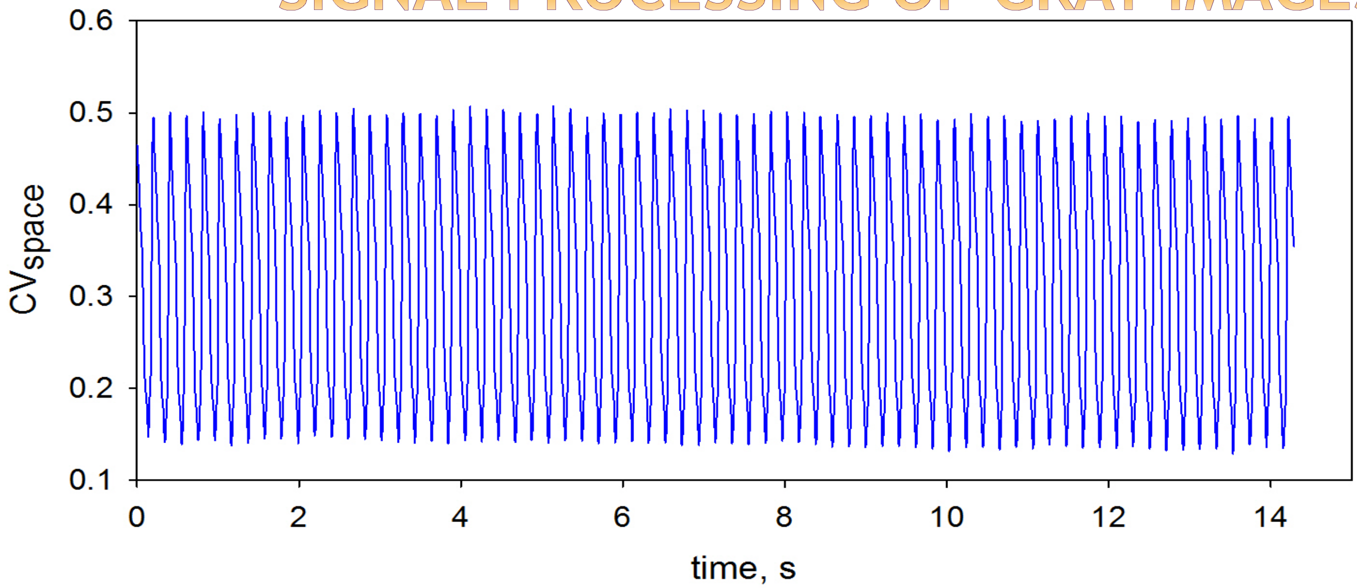
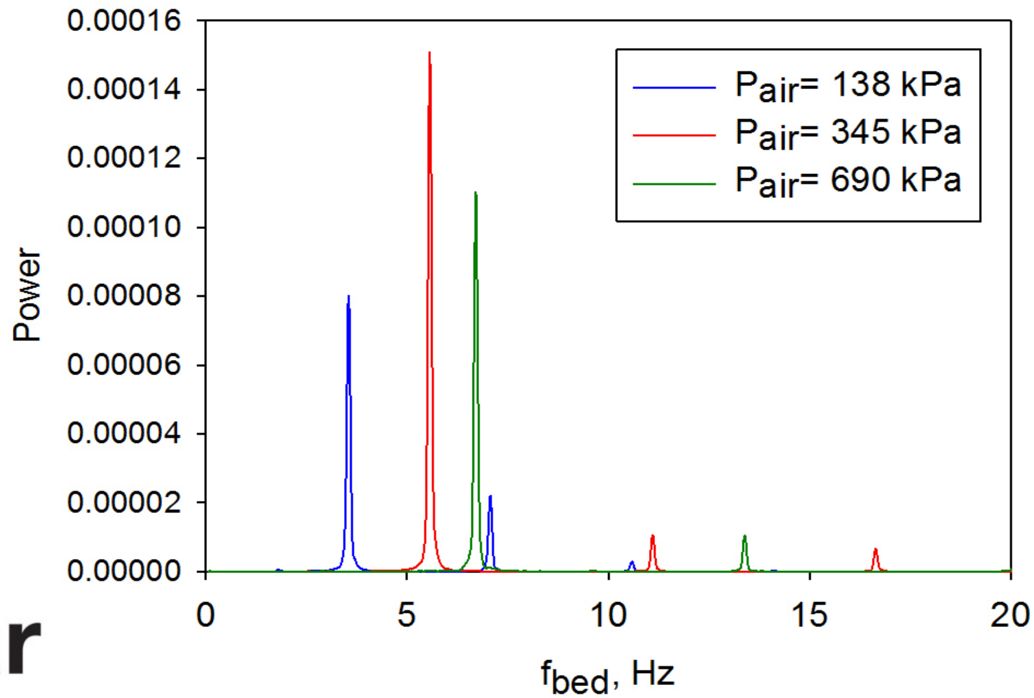
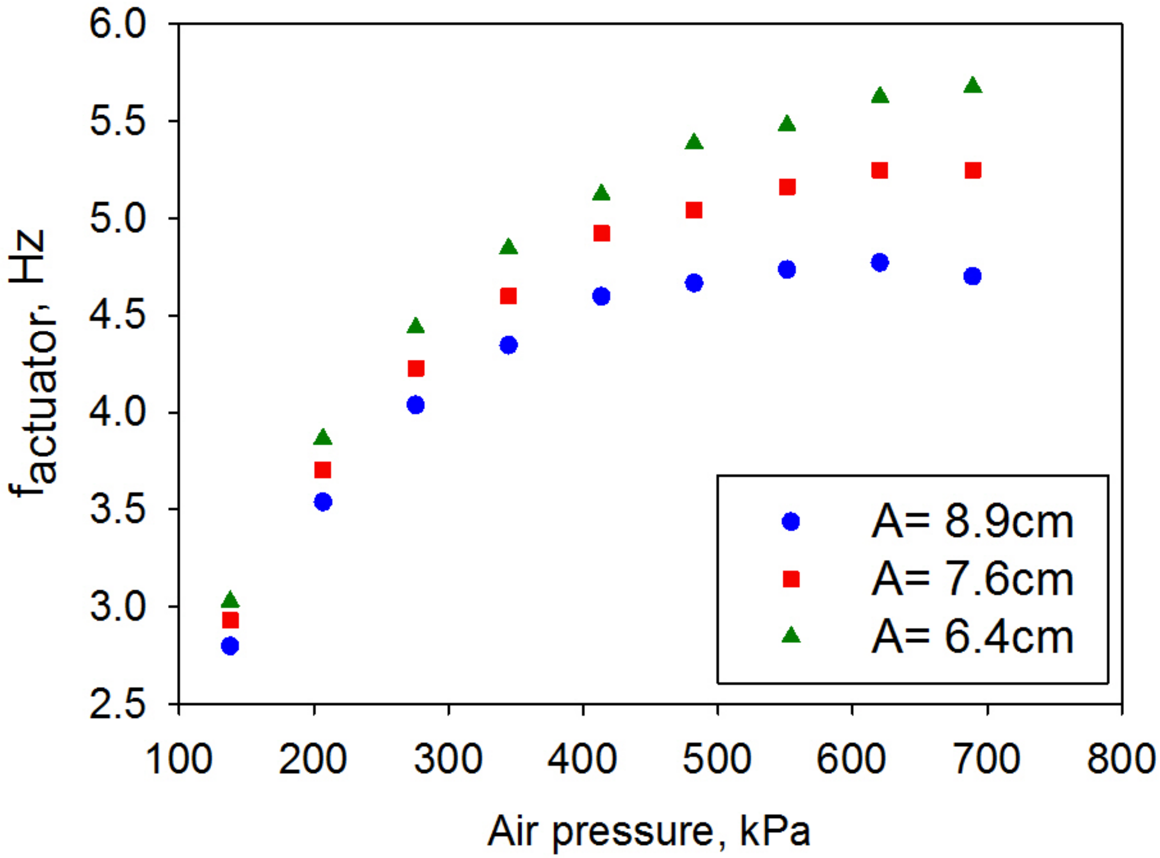
SIGNAL PROCESSING OF GRAY IMAGES





FREQUENCY OF ACTUATOR VERSUS AIR PRESSURE



$$f_{actuator}(Hz) = \frac{No.of\ complete\ cycles}{No.of\ frames} \times \left(\frac{frame}{second}\right)$$

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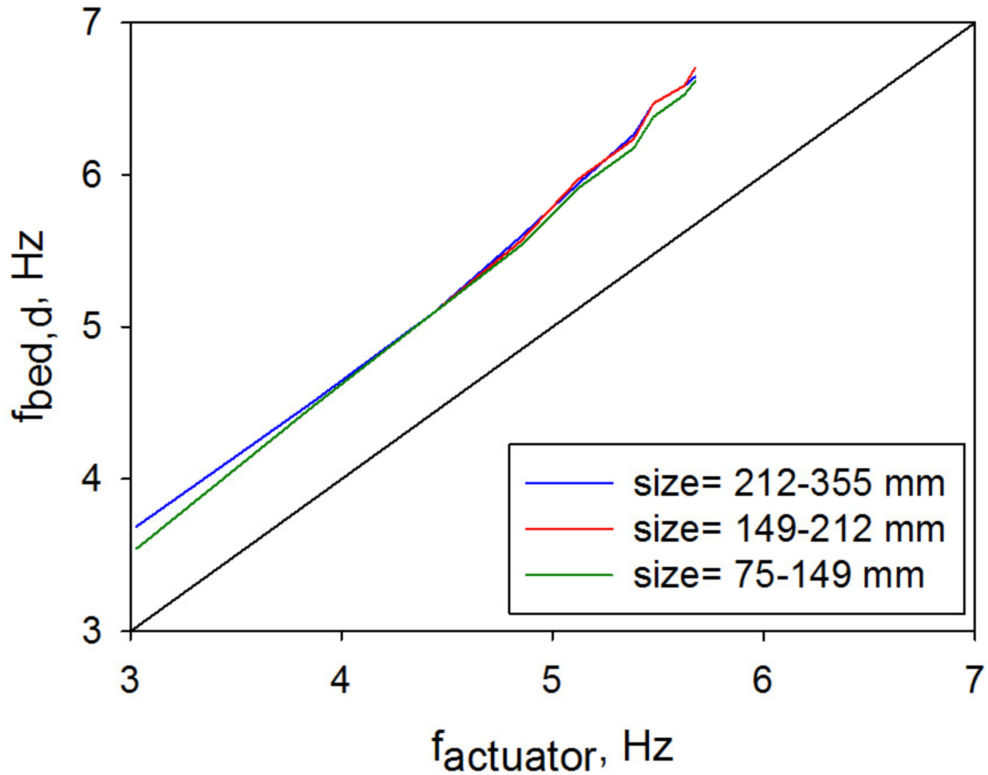
FREQUENCY OF ACTUATOR VERSUS DOMINANT FREQUENCY OF PARTICLES BED



mass of sand particles: 5 g

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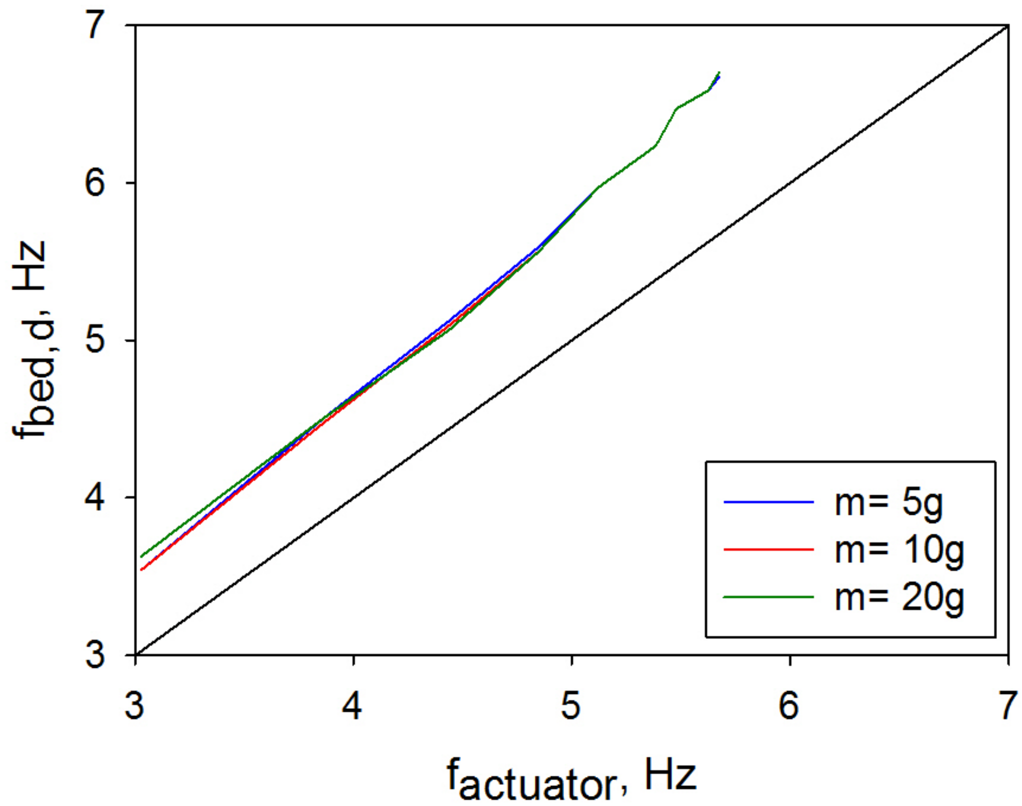
FREQUENCY OF ACTUATOR VERSUS DOMINANT FREQUENCY OF PARTICLES BED



sand particles size: 212-355 μm

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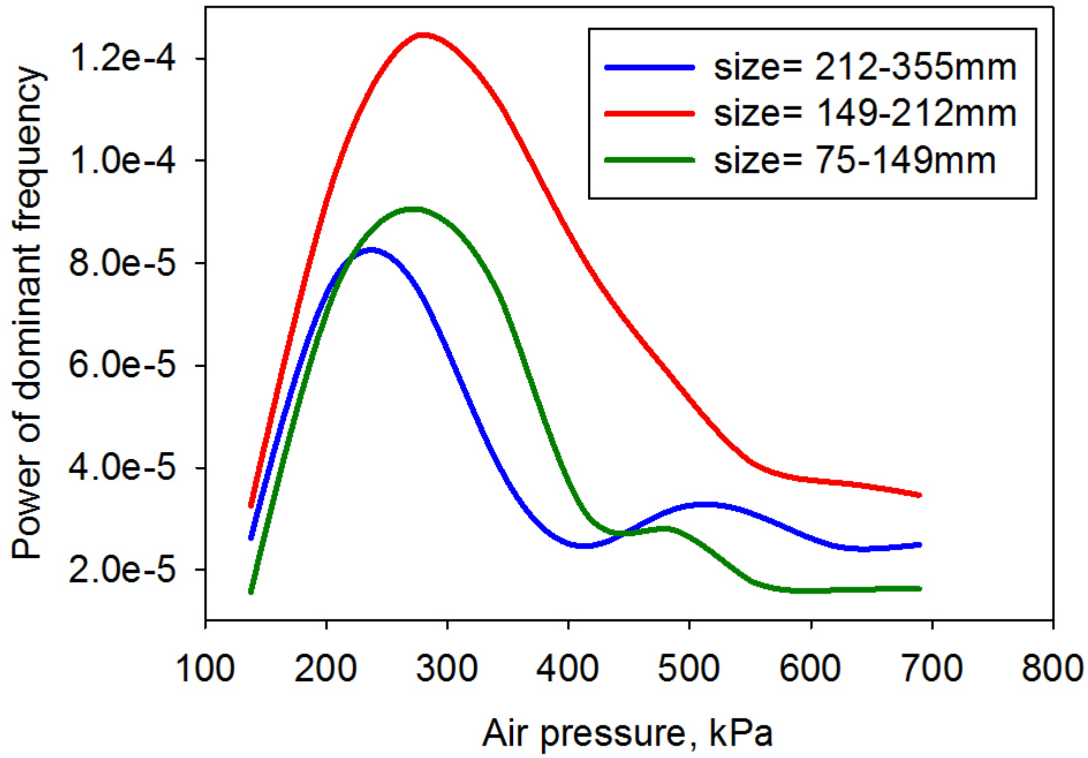
SIGNAL PROCESSING RESULTS



Effect of size distribution of the sand particles on dominant frequency of bed motion

mass of sand particles 5 g; amplitude 6.4cm

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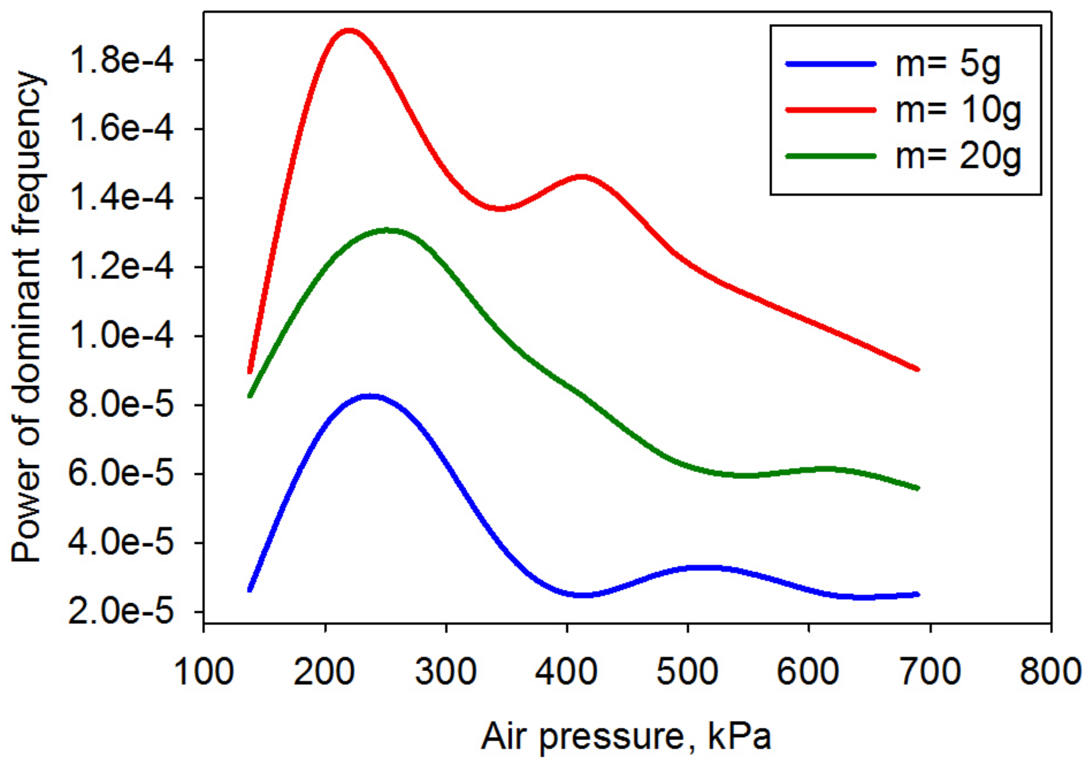
SIGNAL PROCESSING RESULTS



Effect of mass of the particles on dominant frequency power of bed motion

sand particles size 212-355 μm; amplitude 6.4cm

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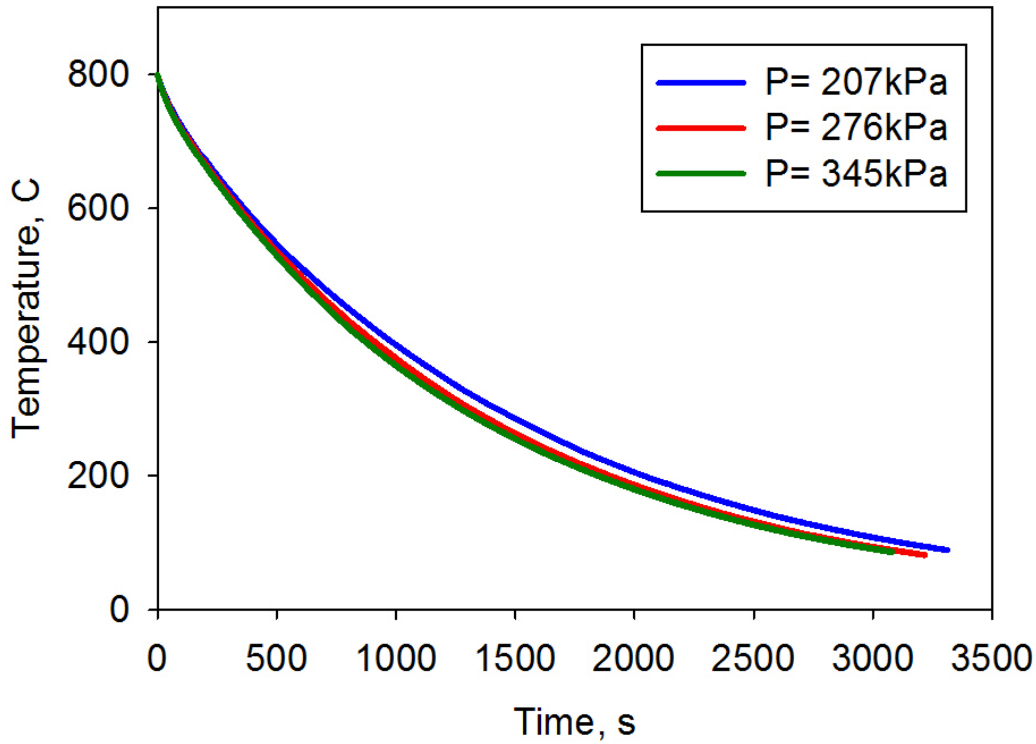
HEAT TRANSFER IN THE JBR
EFFECT OF ACTUATOR FREQUENCY ON COOLING STEP



power outlet 20%, mass of sand particles 10gr, amplitude 6.4cm

Heat balance during cooling step:
Heat lost by particle bed = heat losses
→ heat losses vs. bed temperature

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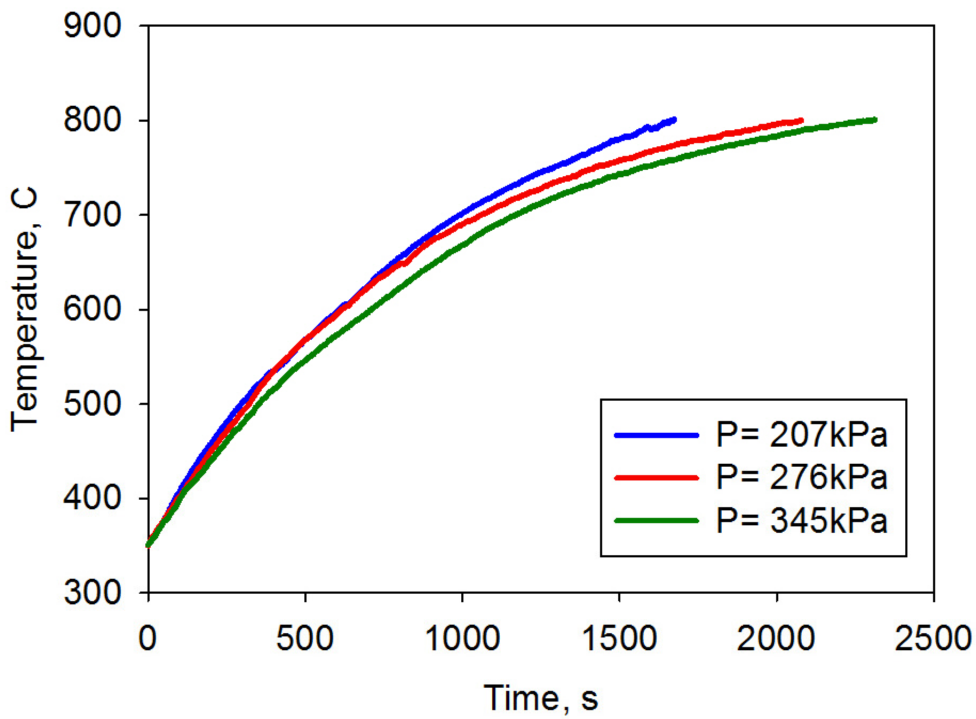
HEAT TRANSFER IN THE JBR
EFFECT OF ACTUATOR FREQUENCY ON HEATING KINETICS



power outlet 20%, mass of sand particles 10 g, amplitude 6.4cm

Heat balance during heating step:

Heat gain of particle bed = electrical power to heaters – heat losses

→ electrical power transferred to in-bed heaters

→ heat transfer coefficient between heaters and bed

HEAT TRANSFER IN THE JBR
TEMPERATURE PROFILE BETWEEN BED AND HEATING WIRES

Power level (%)	T_w (°C)	T_s (°C)	$(T_w - T_s)$ (°C)
10	198	204	6
12	205	210	5
15	246	249	3
20	247	249	2

T_w : temperature on the surface of heating wires

T_s: temperature of bed

Air pressure 207 kPa, sand particles: mass 10g, size 149-212 μm; amplitude 6.4cm

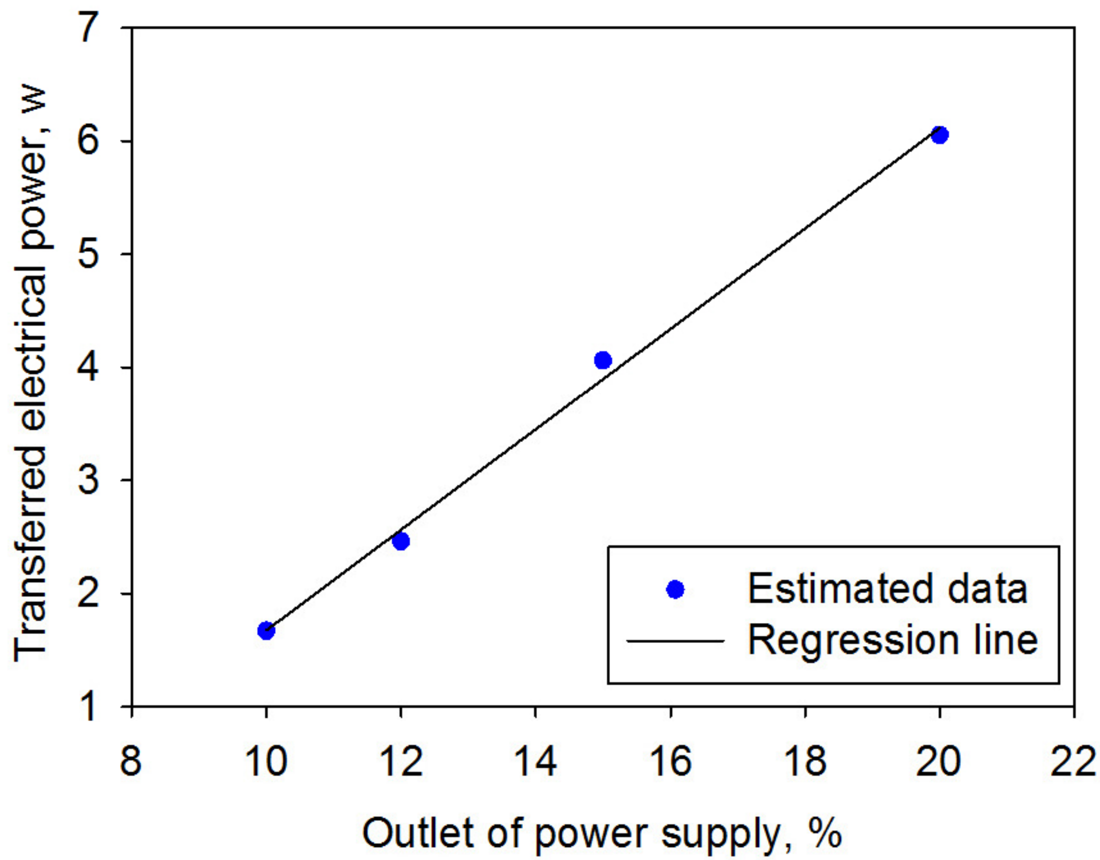
ESTIMATION OF HEAT TRANSFER COEFFICIENTS AND TRANSFERRED POWER VERSUS POWER OUTLET

Power level (%)	$h_0\left(\frac{w}{m^2.\ ^\circ C}\right)$	$P\ (w)$	$h_w\left(\frac{w}{m^2.\ ^\circ C}\right)$
10	0.265	1.67	45
12	0.257	2.46	80
15	0.270	4.06	220
20	0.269	6.05	493

h_0: Heat loss; P: Electrical transferred power; h_w: Heat trasnfer coefficient between wires and bed

Air pressure 207 kPa, sand particles: mass 10g, size 149-212 μm; amplitude 6.4cm

ESTIMATION OF HEAT TRANSFER COEFFICIENTS AND TRANSFERRED ELECTRICAL POWER VERSUS POWER OUTLET



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ESTIMATION OF HEAT TRANSFER QUEFFICIENTS AND TRANSFERRED POWER VERSUS AIR PRESSURE

Air pressure (kPa)	$h_o\left(\frac{w}{m^2.\ ^\circ C}\right)$	$P\ (w)$	$h_w\left(\frac{w}{m^2.\ ^\circ C}\right)$
207	0.269	6.06	493
276	0.290	6.05	492
345	0.299	5.97	486

h_0: Heat loss; P: Electrical transferred power; h_w: Heat trasnfer coefficient between wires and bed

Air pressure 207 kPa; sand particles: mass 10g, size 149-212 µm; amplitude 6.4cm

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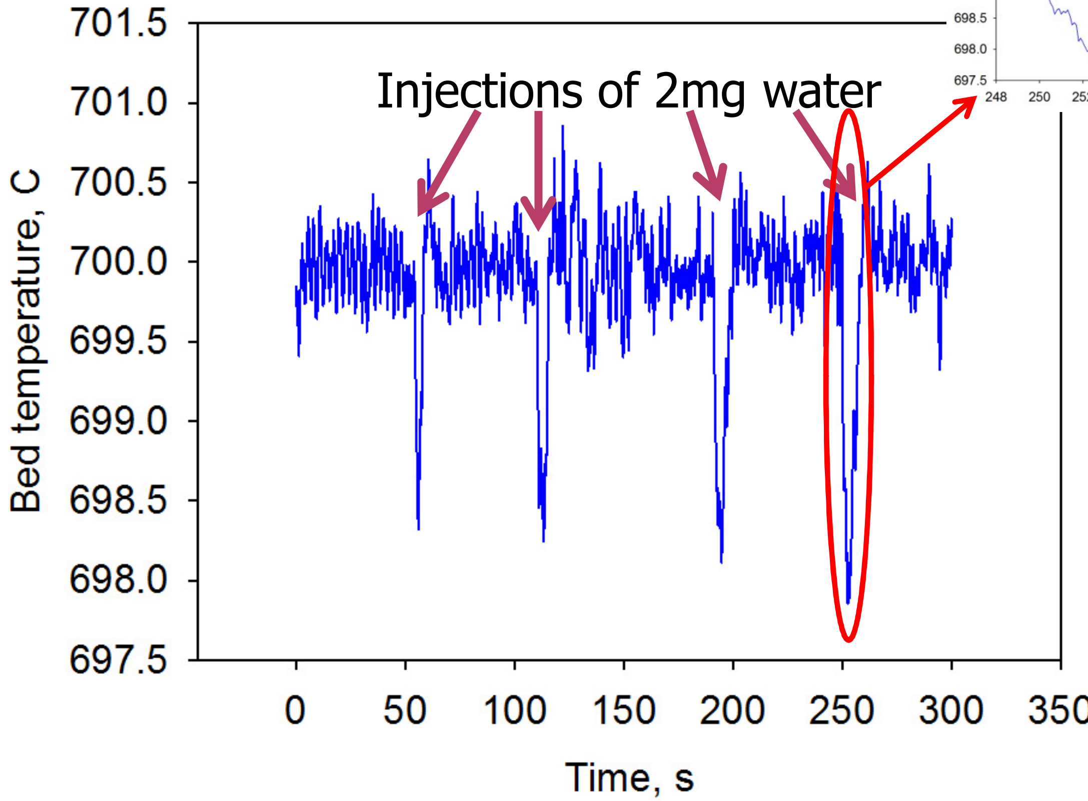
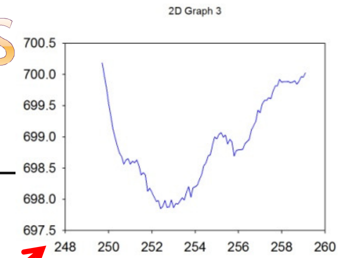
ADVANTAGE OF INDUCTION HEATING FOR ENDOTHERMIC REACTIONS





Close loop temperature control

After water injection, Temperature dropped by less that 2 °C

Temperature recovery time was 4-8 seconds

CONCLUSION

- The jiggle bed reactor (JBR) is a batch micro reactor to test gasification catalysts.
- A linear pneumatic actuator was successfully designed to achieve fluidization conditions in the reaction zone of the JBR.
- A new induction heating system was designed and implemented.
- A new image processing technique was developed to monitor the fluidization dynamics of the catalyst bed.
- The size distribution and mass of the catalyst particles can be optimized for enhanced fluidization.
- Induction heating provides a minimum temperature difference between the heating wires and the catalyst bed.
- the maximum fluidization intensity of the bed corresponds to the highest heat transfer coefficient between the heating wires and the catalyst bed.

THANKS FOR YOUR KIND ATTENTION
GRACIAS POR SU AMABLE ATENCIÓN

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